1996 NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM
JOHN F. KENNEDY SPACE CENTER
UNIVERSITY OF CENTRAL FLORIDA

DISPERSION COMPENSATION OF FIBER OPTIC SYSTEMS FOR KSC APPLICATIONS

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Contract Number NASA-NGT10-52605

July 12, 1996

ABSTRACT

Installed fibers such as those at Kennedy Space Center are optimized for use at 1310 nm because they have zero dispersion at that wavelength. An installed fiber system designed to operate at 1310 nm will operate at a much lower data rate when operated at 1550 nm because the dispersion is not zero at 1550 nm.

Using dispersion measurements of both installed and dispersion compensating fibers, we compensated a 21.04 km length of installed fiber with 4.25 km of dispersion compensating fiber. Using the compensated fiber-optic link, we reduced the dispersion to 0.494 ps/nm·km, from an uncompensated dispersion of 16.8 ps/nm·km.

The main disadvantage of the compensated link using DC fiber was an increase in attenuation. Although the increase was not necessarily severe, it could be significant when insertion losses, connector losses and fiber attenuation are taken into account.

1.0 Introduction

We wanted to increase the information-carrying capacity of an existing fiber-optic communication system. Our system is optimized to operate at a nominal wavelength of 1310 nm and is near its maximum data capacity. Replacing the existing system with a new system is not a practical option, nor is the use of multiple wavelengths. The use of multiple wavelength requires expensive equipment that is not always easily obtained, and the modification to the existing system could be complicated.

Recent developments in fiber optic technology are not always optimized for the 1310 nm wavelength. The invention of the erbium-doped fiber amplifier[1] (EDFA) has changed fiber-optic system design because its has reduced the importance of loss in fiber systems. Most EDFAs operate at a wavelength around 1550 nm; therefore, many recent developments in fiber optic technology have been for the 1550 nm wavelength.

An installed fiber system designed to operate at 1310 nm will operate at a much lower data rate when operated at 1550 nm. Installed fibers such as those at Kennedy Space Center (KSC) are optimized for use at 1310 nm because they have zero material dispersion at that wavelength. However, if components operating at 1550 nm are used with this fiber, material dispersion will dominate and the speed (bit-rate) of the system will decrease when compared to the bit-rate at 1310 nm.

The most straightforward way to reduce the effect of dispersion is to use dispersion compensating (DC) fiber. DC fiber has the characteristic that the dispersion at 1550 nm is generally opposite to that of the fiber it is to compensate. DC fibers can be designed to compensate the dispersion of standard fibers (optimized for 1310 nm) through their index of refraction profile.[2-3] Using the proper length of DC fiber in series with a standard fiber, the total dispersion may be zero. Most references in the literature on this topic deal with the use of DC fibers in series with standard fibers and EDFAs to increase the distance between repeaters of a fiber system.[4]

2.0 Chromatic dispersion

Chromatic dispersion is caused by a variation in the index of refraction of a material with wavelength. Since it can cause pulse spreading in an optical communication system, it can degrade system performance. This is shown schematically in Fig. 1. As a pulse of light travels down an optical fiber, different wavelengths travel at different speeds. By the time the pulses arrive at the receiver, they may have spread over several bit periods and cause errors. To reduce

the effects of dispersion, we must somehow compensate for its efffect, or transmit data at a lower rate. In this section, we discussed some of the theory of chromatic dispersion followed by the relationship between dispersion and bandwidth.

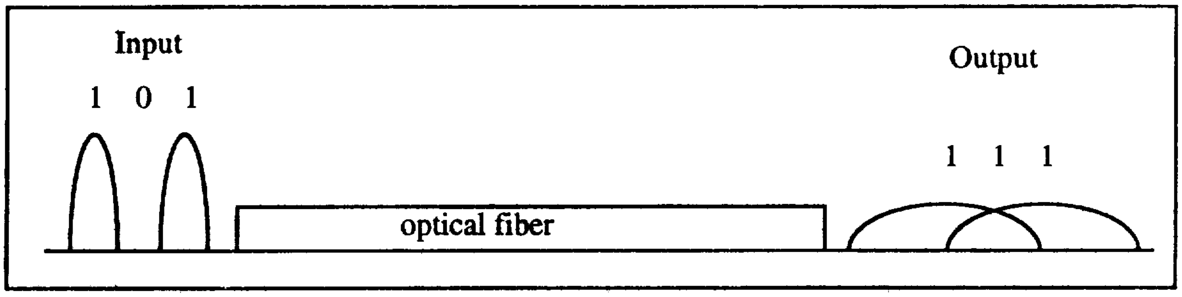

Figure 1 Error caused by chromatic dispersion in an optical fiber system

The dispersion of a fiber is defined as the broadening per unit spectral width for a fiber of unit length.[5] It is based on the second derivative of the index of refraction as a function of wavelength as is usually written as

$$D = -(\lambda/c)(d^2n/d\lambda^2), \quad (1)$$

where c is the speed of light. The units are ps/km·nm, which is the amount of broadening in picoseconds that would occur in a pulse with a bandwidth of one nanometer while propagating through one kilometer of fiber. The maximum bandwidth of a system can be written as

$$\text{maximum bandwidth} = 1/\,|\,LD\Delta\lambda\,|, \quad (2)$$

where L is the length of the fiber, and $\Delta\lambda$ is the spectral width of the source. For example, given a length of fiber of 10 km, D = 100 ps/km·nm, and a source with a spectral width of 1 nm, the maximum bandwidth is 1 GB/sec. The bandwidth will increase linearly with a decrease in dispersion or length of fiber.

3.0 Compensation of chromatic dispersion using dispersion compensating fibers

To compensate for the dispersion of a standard fiber at a particular wavelength, a DC fiber can be used in series with a standard fiber as shown in Fig. 2.

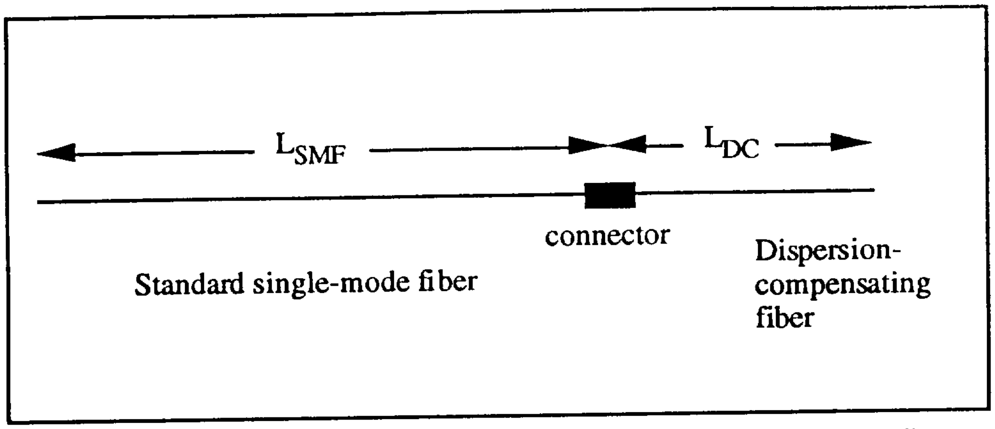

Figure 2 Schematic diagram of compensation of standard fiber

In this case, the total dispersion is

$$\Delta\tau = L_{SMF}D_{SMF} + L_{DC}D_{DC}, \tag{3}$$

where L_{SMF} and L_{DC} are the lengths of the standard and DC fibers, and D_{SMF} and D_{DC} are the dispersion of the standard and DC fibers respectively. Because length is always positive, the total dispersion will go to zero at the wavelength of interest if the DC fiber has a negative dispersion of the proper magnitude. To compensate a fiber of length L_{SMF}, we set $\Delta\tau$=0 in Eq. (3) and solved for L_{DC}. We found that the length of DC fiber needed was

$$L_{DC} = - L_{SMF}D_{SMF}/D_{DC}, \tag{4}$$

where the dispersion of the DC fiber is negative at the wavelength where compensation is to take place.

For a length of standard fiber, the length of DC fiber needed for compensation at a particular wavelength is the negative of the ratio of the dispersions at that wavelength. This was described as a compensating factor and written as

$$\text{compensating factor (CF)} = - D_{SMF}/D_{DC}, \tag{5}$$

where small numbers lead to short lengths of DC fiber.

The figure of merit (FOM) measure in a sense measures the efficiency of a fiber.[6] It is defined as, the ratio of the dispersion of the DC fiber and its attenuation, at a particular wavelength. The FOM can be written as

$$\mathrm{FOM} = D_{DC} / \alpha_{DC}, \tag{6}$$

where α_{DC} is the attenuation of the DC fiber. A more negative number indicates better efficiency.

4.0 Dispersion and attenuation measurements of fibers

To measure dispersion we followed the corresponding fiber-optic test procedure (FOTP) standard[7] and used a York S18 chromatic dispersion system. The fiber we were attempting to compensate was Corning SMF-28CPC3 single-mode fiber. We measured its characteristics with a fiber of length 8.87 km. The zero-dispersion wavelength was found to be 1323.02 nm with a slope of 0.0926 ps/nm^2·km at that wavelength. The dispersion at 1550 nm was found to be 16.83 ps/nm·km and the attenuation 0.37 dB/km at 1550 nm.

We performed dispersion measurements on two types of DC fiber. They were both labeled as Corning FiberGain Module fiber. Therefore, we referred to the fibers here as FGM1 and FGM2. We performed five experiments and averaged their results. We measured a length of 1.01 km of FGM1 fiber and found its dispersion at 1550 nm to be -115.0 ps/nm·km. We measured a length of 4.25 km of FGM2 fiber and found its dispersion at 1550 nm to be -79.13 ps/nm·km. Note that both types of fibers each had SMF fiber pigtails with two permanent connectors measuring a total of approximately 1.23 m. A graph showing the dispersion data in Fig. 3.

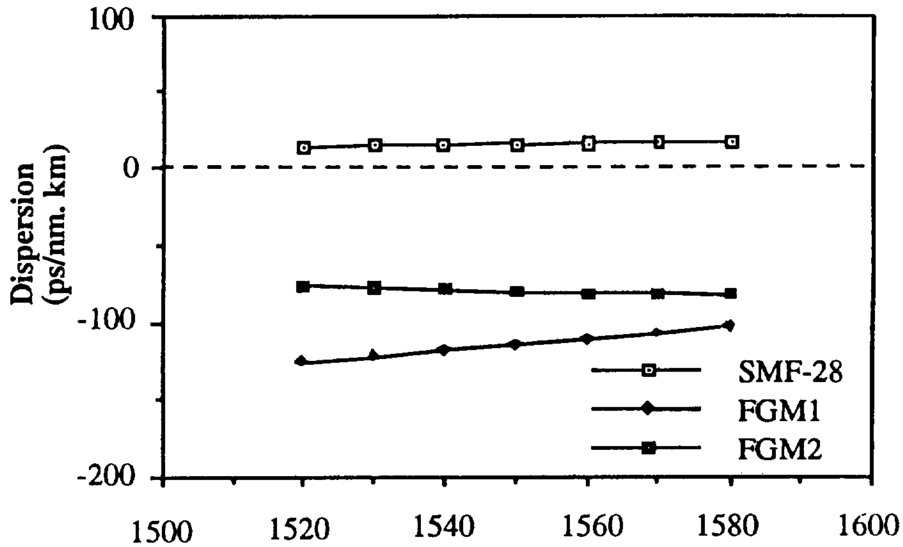

Figure 3 Dispersion data in vicinity of 1550 nm

A summary of the measurements is given in Table 1.

Table 1 Characteristics of dispersion-compensating fibers

Fiber	Compensating factor	Dispersion at 1550 nm (ps/nm·km)	Dispersion slope at 1550 nm ($ps/nm^2 \cdot km$)	Attenuation at 1550 nm (dB/km)	FOM at 1550 nm (ps/nm·dB)
SMF-28CPC3	---	16.83	0.060	0.37	---
FGM1	0.147	- 115.0	0.367	1.8	-63.9
FGM2	0.213	- 79.13	-0.106	0.75	-106

5.0 Compensated fiber-optic links

We calculated the dispersion of compensated links in the vicinity of 1550 nm. The results are shown in Fig. 4.

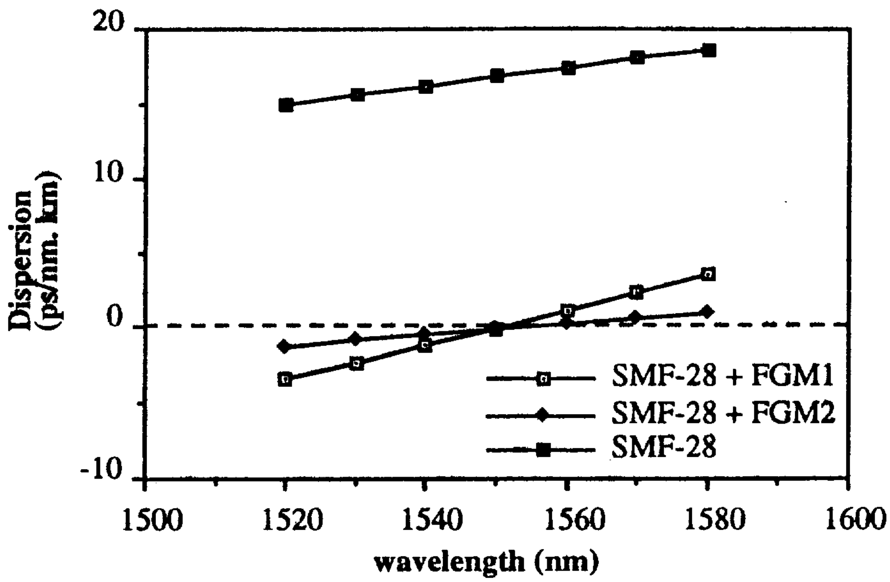

Figure 4 Calculated dispersion of compensated links for two types of DC fiber

A summary of the calculations on compensated links is given in Table 2.

Table 2 Characteristics of dispersion-compensated links

Fiber link	Dispersion slope at 1550 nm ($ps/nm^2 \cdot km$)	Attenuation at 1550 nm of total fiber (dB/km)
uncompensated	0.0601	0.37
SMF-28 + FGM1	0.114	0.55
SMF-28 + FGM2	0.0373	0.44

5.2 Selected link

To test a dispersion compensated system in a realistic setting, we connected a fiber-optic link using existing installed fibers at KSC. We used two links in series that both originated from the engineering development lab (EDL) that measured approximately 5.2 km, and 15.8 km. The links were identified by numbers on the fiber optic panel, 39-40, and 43-44, and their circuit numbers, 6TEM9948, and 6TEM9945 respectively. The links were connected with a 1 m length of SMF fiber, and connected to the dispersion measuring instrument through a total length of

49.2 m of SMF fiber. The total fiber loop went through the following KSC buildings: EDL-O&C-CDSC-O&C-EDL-CDSC-VABR-CDSC-O&C-EDL. The total length of fiber was measured to be 21.04 km.

5.3 Measurements of compensated link

We used the total length of the FGM2 fiber to compensate the selected link; ideally, the fiber would compensate 20 km so there should be a small dispersion in our link. We added the FGM2 fiber to the selected link and measured the total loop to be 25.29 km.

Using Eq. (3) we calculated the dispersion of the compensated link to be 0.704 ps/nm·km. We performed 25 dispersion measurements with the FGM2 fiber at the source side of the dispersion measuring instrument and found the dispersion to be 0.582 ps/nm·km, with a standard deviation of 0.304. With the FGM2 fiber on the opposite end, we found the dispersion to be 0.407 ps/nm·km, with a standard deviation of 0.408. Therefore, it appears that the difference in measurements is within statistical error and we used the average of the 50 experiments for the value of the measured dispersion as 0.494 ps/nm·km. The dispersion results of the compensated link are shown in Table 3.

Table 3 Measurements of dispersion-compensated links

Fiber link	length (km)	calculated dispersion (ps/nm·km)	measured dispersion (ps/nm·km)
uncompensated	21.04	-	16.83
compensated SMF-28 + FGM2	25.29	0.704	0.494 σ=0.371

6.0 Summary and conclusion

To compensate for the dispersion of an installed standard fiber, a DC fiber can be used in series with the standard fiber. Because the dispersion of SMF fiber is positive, we need a fiber with a dispersion that is negative for compensation. Large negative dispersions of the compensating fiber will lead to short lengths of DC fiber and reduce space requirements.

Using measurements of dispersion for both SMF and DC fibers we compensated a 21.04 km length of installed SMF fiber with 4.25 km of DC fiber. Using the compensated fiber-optic

link, we reduced the dispersion to 0.494 ps/nm·km, from an uncompensated dispersion of 16.8 ps/nm·km. We did not find a difference in dispersion measurements when the DC fiber was placed at the beginning or end of the link.

The main disadvantage of the compensated link using DC fiber was an increase in attenuation. Although the increase was not necessarily severe, it could significant when insertion losses, connector losses and fiber attenuation is accounted for.

7.0 References

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